Background and objective

Due to hydrogen's (H_2) high gravimetric energy density it has the potential to aid in the transition to a carbon-free future, as it potentially could replace fossil fuel energy carriers in applications such as aviation, shipping, and heavy transport. However, at standard conditions, H_2 has a low volumetric energy density which makes it inadequate for applications where storage size matters. In order to improve the economics of H_2 transportation, it is compressed to 200-700 bar or converted into a liquid phase by cooling it down to −253 °C, (at atmospheric pressure). Liquid hydrogen (LH_2) is a promising option compared to compressed gaseous hydrogen in terms of volumetric energy storage, but the energy use related to cryogenic cooling of H_2 is too high to make it cost-competitive with fossil fuels such as LNG, gasoline, and diesel.

Commercialized LH_2 production plants typically consist of a hydrogen Claude liquefaction cycle that is integrated with an open liquid nitrogen vaporization (LIN) pre-cooling cycle, were nitrogen is supplied from an air distillation process. The average production capacity of LH_2 plants is in the range of 5-10 tonnes per day, which is low compared to commercialized LNG production. Prediction indicates that to decrease the power consumption of LH_2 production, increased train capacity is important in order to shift the cost towards operational expenditure. Also, increased production capacity can justify the increased capital requirement associated with a more advanced and energy-efficient pre-cooling cycles. To increase LH_2 train production capacity, the dependency on the open LIN pre-cooling cycle should be removed due to the limited cooling capacity. Earlier work suggests improving the process by replacing the LIN pre-cooling cycle with a single mixed refrigerant cycle, dual mixed refrigerant cycles, or auto-cascade cycle. The most significant exergy destruction of a hydrogen Claude cycle is related to compression and heat rejection. It is claimed to be beneficial to attribute significant portions of the cooling load in a pre-cooling cycle, which often is found to have a higher exergy efficiency than the hydrogen Claude cycle, thereby reducing the specific energy use.

The overlaying intention of this master's thesis is to find the optimal preccoling temperature in a hydrogen liquefaction process, emphasizing MR precooling cycle modeling and exergy efficiency optimization. Therefore, an estimated thermodynamic model for equilibrium hydrogen must be created to account for the exothermic ortho-parahydrogen conversion throughout the liquefaction process. To evaluate the performance of the optimal pre-cooling temperature configuration, an overall and component-based exergy analysis will be performed for the optimal pre-cooling temperature configuration.

The following tasks are to be considered:

1. Literature review on LH_2 processes.
2. Creating and implementing a thermodynamic model in to Aspen HYSYS to estimate the behavior of equilibrium hydrogen.
3. LH_2 process modeling of MR precooling cycles and a hydrogen Claude refrigeration cycle in Aspen HYSYS.
4. Optimization of selected process layouts for the LH_2 liquefaction cycle in the range 80-120 K, with the intention of finding the optimal precooling temperature.
5. Perform an overall and component-based exergy analysis for the optimal pre-cooling temperature configuration in order to assess the process performance.